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BUREAU OF MINES
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INFORMATION CIRCULAR

MECHANIZED MINING BRINGS NEW ELECTRICAL HAZARDS

BY

E. J. GLEIM AND H. B. BRUNOT

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MECHANIZED MINING BRINGS NEW ELECTRICAL HAZARDS[1]

By E. J. Gleim[2] and H. B. Brunot[3]

INTRODUCTION

In the mining of coal the trend is toward more and more mechanization. This increased use of machinery to replace hand labor is assuming many new forms and presents a constantly changing aspect. Safety engineers must be alert if the many electrical problems resulting from these new installations are to be handled safely. Some of these problems present possible electrical hazards that may be overlooked by the safety engineer unless they are called to his attention by one who has made a special study of the conditions.

The foregoing is especially true of conveyor systems of mining. The terms "conveyor systems" and "conveyor mining" as used in this paper refer to those systems in which various types of conveyors are employed to transport coal away from the working place. In some mines this means complete elimination of track, cars, and locomotives. In others it means that conveyors take the coal from the working place to a convenient loading point, from which transportation is completed by cars and locomotives.

In the urge to try methods that will produce the most coal at the lowest cost it must not be forgotten that the standards of safety applicable before mechanization became so popular are not now broad enough in scope to embrace the conditions of the new methods.

Under some of the modern systems a number of cuts are made in a working place each day with a mining machine where formerly only one cut was made. This suggests the possibility of liberating more gas than formerly in 24 hours in a given working place, with the probability that ventilation must receive greater consideration. Likewise, more coal dust will be thrown into suspension in the same period unless steps are taken to allay it, as by spraying the cutter bits with water while mining machines are in operation. Rubber-tired equipment may contribute materially to the making of fine coal dust by crushing the coal under the tires. Therefore, it is essential to apply

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water and rock dust or take equally effective measures to safeguard against ignitions of dust.

In the conventional room-and-pillar system of mining before mechanization it was customary to have one machine follow another in performing the successive operations necessary in extracting the coal. Usually the trailing cable for each was coiled or reeled as the machine came out of the room. Thus the cable was exposed to possible damage by roof falls only for the duration of its brief stay in the room to perform the necessary operation. In conveyor systems of mining usually several cables, instead of just one, are exposed to possible damage by roof falls; and as the machines do not leave the room at the completion of each operation this means that cables are exposed considerably longer in conveyor systems than in room-and-pillar systems. Therefore greater care must be exercised in the selection, installation, and protection of the cables for this service.

Transportation of coal by conveyors and rubber-tired cars is reducing the amount of trolley wire required for operation of locomotives in mines employing such equipment. Where cutting and other machines formerly were connected to the trolley system by means of trolley taps and rail clamps such methods made necessary careful consideration of a safe means for bringing branch circuits from the trolley system to a convenient point of connection for the various machines. A connection box for terminating all cables entering a room at a common point was soon in demand. Some of the requirements demanded for such a box were (1) a means of cutting off power from all cables in one operation, (2) individual overload protection for each cable, (3) simple arrangement for disconnecting one cable without disturbing others, (4) connection plug or equivalent designed to minimize the possibility of connecting a cable in the wrong place where it would not have adequate overload protection, (5) an interlocking arrangement to prevent working on live terminals of branch circuits, and (6) size and weight of the whole satisfactory for portability, particularly when used in low seams. Designs have been placed on the market to meet this need, but undoubtedly there will be other designs as improvements develop with the demands of the industry.

Conveyor Mining Hazards

The various schemes of mechanical mining that require the presence of several machines and a number of men in the same working place all at one time tend to enhance both the mechanical and electrical hazards. It is not the object of this paper to enumerate all of the various combinations of machines and circuits that may give rise to extra hazards, but to indicate, first, that the presence of two machines in one place may more than double the hazard from failure of insulation and, second, to emphasize that increase in mechanization must be accompanied by a commensurate increase in precautions to avoid unsafe conditions.

The Bureau's engineers receive reports from various sources relating to hazardous conditions that develop in electrical mining machinery under diverse conditions. Information from such sources is studied and augmented by inspections in the mines. In recent years an increasing number of instances have

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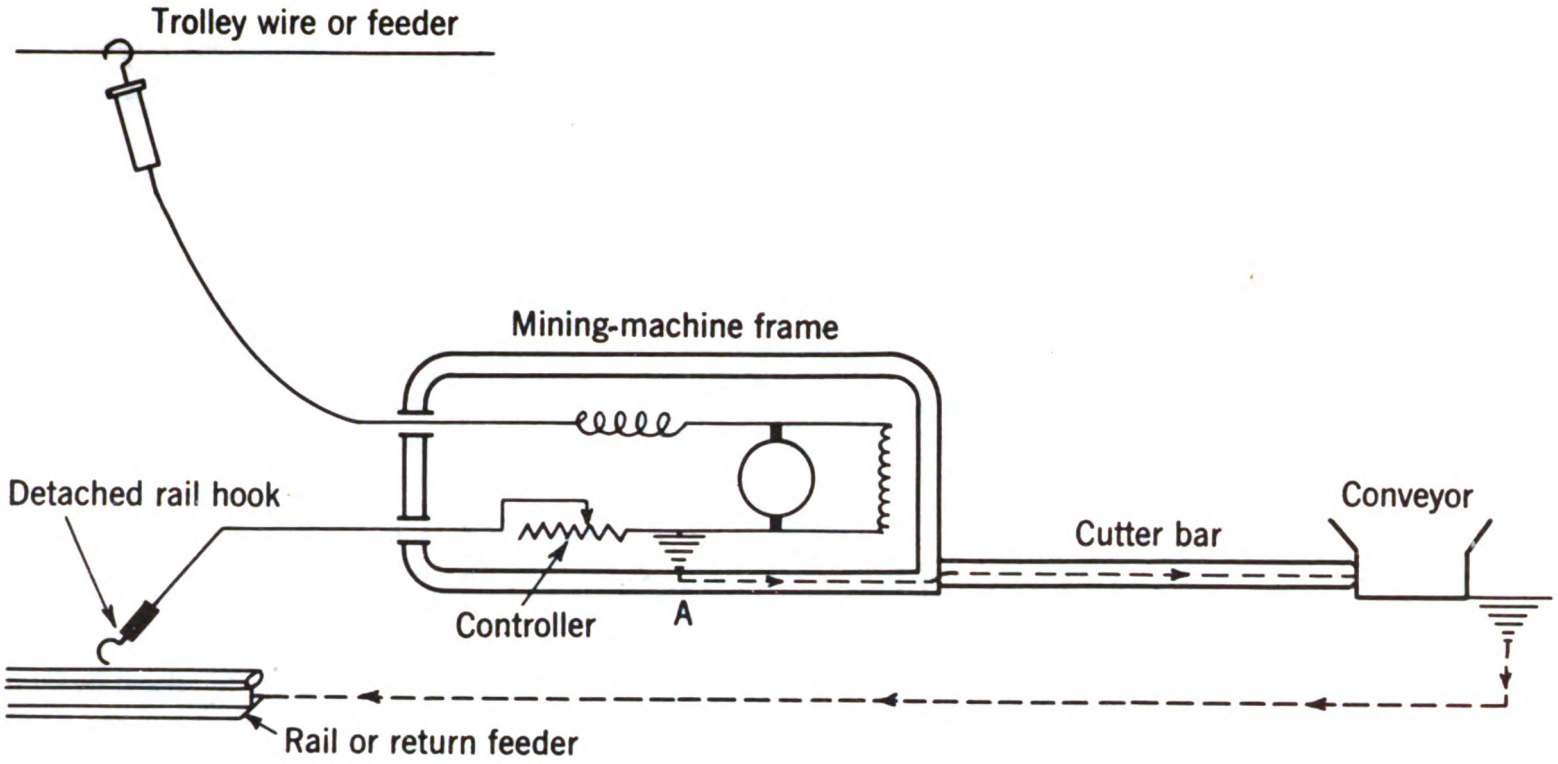

Figure 1.- Dangerous condition of mining-machine frame caused by dislodgment of rail hook.

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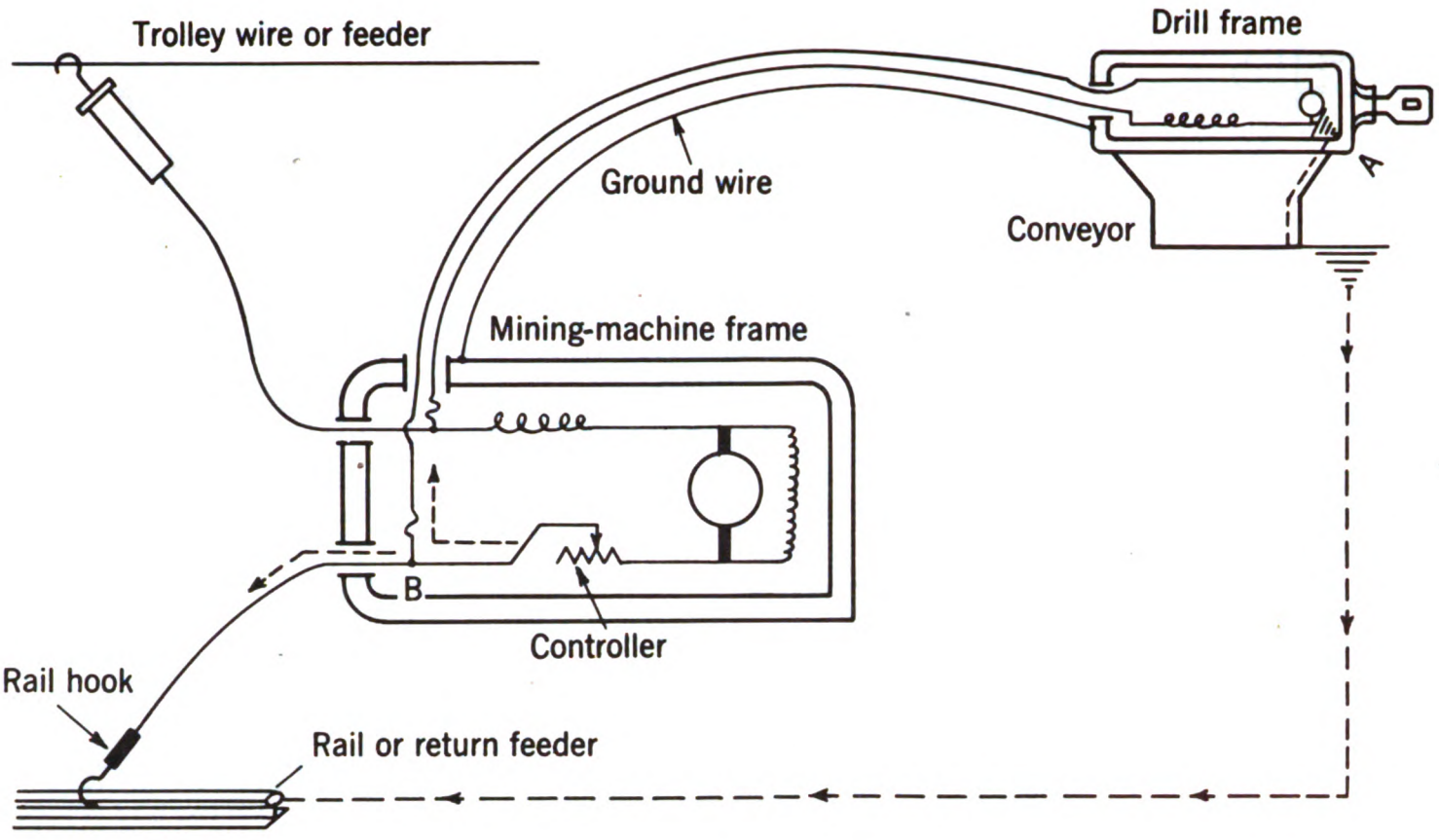

Figure 2.- Defect in drill insulation at "A" shown causing the mining current to divide at "B."

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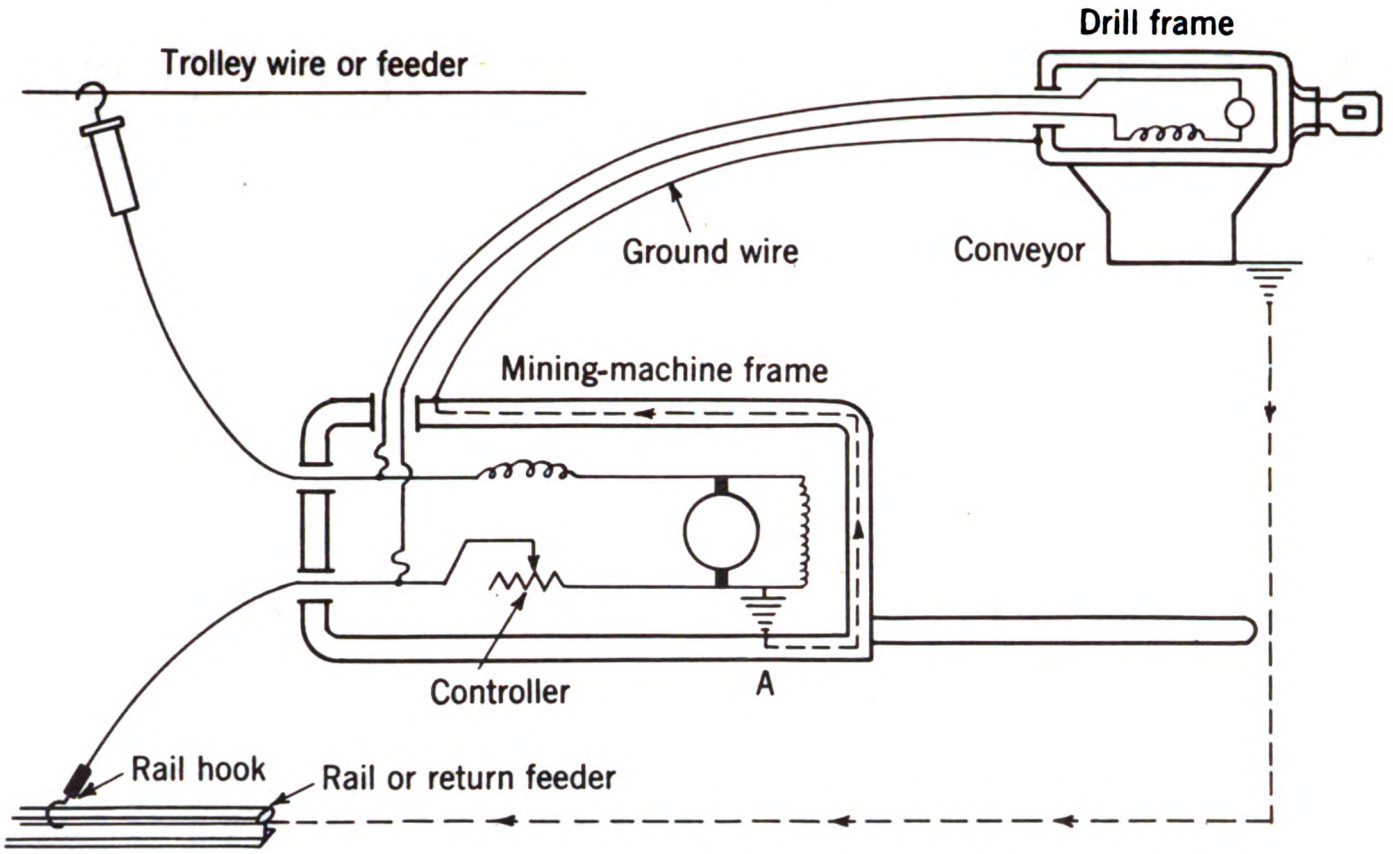

Figure 3.- A fault occurring at point "A" causes current to follow direction of the dotted line.

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been reported of trouble arising when two or more machines were present in the same working place at the same time. Hazards of this general nature are not new but fortunately in the past have occurred more or less infrequently.

These additional electrical hazards may be divided into two groups - open sparking between normally non-current-carrying parts and overheating of conductors that would not occur if the machine were alone.

As an example of the first group may be cited the possible results of a failure of insulation at or near the grounded terminal of a machine supplied from a grounded direct-current system. This may not seriously hamper operation of the machine. In fact, such an occurrence may not even become evident to the machine runner for an indefinite period in the ordinary course of work. Nevertheless, the machine is in a hazardous condition. If, as is so frequently true, the machine frame is not adequately grounded by a separate conductor of ample size any disturbance of the return circuit, such as might result from a broken or loose rail bond or dislodgment or loosening of the rail hook, may cause the frame to be charged to a dangerous potential. Under such circumstances the operator not only may receive a fatal shock, especially if he is also in contact with a conveyor or other fairly well-grounded machine frame, but open sparking between the faulty machine and the conveyor may, if explosive gas is present, lead to a disastrous explosion with the attendant destruction of life and property.

In addition to sparking, contact between a grounded direct-current mining machine and a conveyor has been known to start the machine or cause it to continue running even after the controller has been disconnected. This is possible when the controller is connected only in the line that goes to the return. By referring to figure 1 it will be seen how contact between a defective machine and a conveyor can give rise to the hazards just described. In this diagram the dotted line shows the path taken by the current through the defect at "A."

Any ground in the machine may create such hazards; but some grounds make their presence evident by causing distress in the machines' operation, by odor of burning insulation, or by stopping the machine entirely. These grounds may therefore sometimes prove less hazardous to life and property by making themselves manifest sooner and thus demanding correction.

As an example of conditions that might result in overheating of conductors consider a coal-cutting machine, a conveyor, and a hand drill in the same room, the drill receiving its power through a connection on the mining machine. Failure of the drill insulation could provide a parallel path for the return current from the mining machine through the small drill cable. This is illustrated in figure 2, in which a defect in the drill insulation at "A" causes the mining-machine current to divide at "B." If the drill is not properly protected by a fuse this cable could be overheated. Again, when the drill frame is grounded to the cutting-machine frame to protect the driller from shock the ground wire from the drill might readily become a parallel path for return current from the cutting motor in case of insulation failure in the latter. Figure 3 shows how it is possible for a hazard to develop

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from a fault occurring at point "A" which causes current to follow the direction of the dotted line. Open sparking between the conveyor and drill or cutting-machine frames also is one of the possible sources of danger in such a combination. Moreover, it will be seen by reference to the diagram that should the rail connection become loose or dislodged it would be possible to burn the drill cable by current through the ground wire. It is for this reason that the Bureau requires the fusing of both sides of such branch circuits to drills and headlights.

Previous to conveyor mining it was customary to operate mining machines with cable-reel trucks, which served a double purpose. In addition to providing a means of transporting the machine from room to room they also carried a switch and fuse, or equivalent, to protect the machine. With the adoption of conveyor mining the truck was no longer required for moving the machine, and as track was not laid in the rooms the truck was too large and unwieldy to be taken into the rooms. Consequently there have been many installations in which the machine operator had no means other than the controller of cutting off the power near at hand. Furthermore, the overload protection, if any, was no nearer than the end of the trailing cable. Thus an unsafe operating condition arose. If a machine should suddenly "jump out" of its place because the bits strike some hard substance while the machine is being sumped in, it might get out of control and knock out posts or catch the operator. Without an independent switch for stopping the machine considerable damage or severe injury to men might result before some one could disconnect the trailing to stop it. In such emergencies, and especially when the coal seam is low, considerable time elapses before a man can travel 300 feet or more to reach the point where he can disconnect the cable.

Another hazard that must not be overlooked is the possibility of flash-overs in drum controllers on some of the older-type 500-volt machines. Under certain conditions the arcing that follows the flash-over can burn a hole in the controller case, and disconnecting the controller will not stop the flow of current. Here, again, the absence of a switch is a serious handicap to prompt action in an emergency.

Corrective Measures

In a gassy mine special precaution must be taken against ignition of gas and dust by sparks from the machines and their cables during operation in the mine. Important steps in preventing such ignitions are the replacement of "open"-type machines with explosion-proof types approved by the Bureau of Mines and their proper maintenance to preserve safety.

During the past 25 years the Bureau has approved about 300 motor-driven machines intended for use at or near the working faces of dusty or gassy mines. These machines are constructed to meet the provisions of schedules giving the minimum essentials considered necessary for safety. The original basic idea of such designs was to provide explosion-proof enclosures for the electrical parts capable of preventing the spread of an explosion of mine gas that might occur inside to the surrounding explosive mixture. During the first few years this problem was studied carefully. Today knowledge gained from original

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research and from testing hundreds of designs makes it comparatively certain that satisfactory explosion-proof enclosures can be provided for all types of machines.

The electrical circuits and wiring on the first permissible machines were comparatively simple. In general, these machines carried only a switch and fuse and a simple drum or disk-type manual starter in addition to the motor and starting resistor, and in many instances both the resistor and starter compartments were integral with the motor casting, so that little if any external wiring was present. The terminal connections and the trailing cable presented the chief wiring hazards. The latter is still one of the chief hazards, although better cables have been developed.

As mechanization has advanced the design of mining machinery has become progressively more complicated, until today there are single machines with as many as 40 explosion-proof compartments. Corresponding increase in the amount of wiring on these machines now makes adequate protection of the circuits between the explosion-proof enclosures one of the chief problems. Wiring must be so placed and protected by conduit and guards that mechanical injury or deterioration of rubber insulation from contact with oil is minimized. Adequate overload protection for the numerous branch circuits for small motors, headlights, and the control devices must be devised and provided. This problem also is being solved successfully for any given machine as an individual unit.

Production of mining machinery that initially is reasonably safe for use in dusty and gassy mines devolves primarily upon the manufacturers and the Bureau of Mines. Safe application and the necessary maintenance to preserve safety devolve principally upon the user and the various State inspection departments. But full cooperation between these groups is essential if optimum safety is to be achieved.

In designing permissible mining machinery it has been tacitly assumed that each machine would be used as a separate unit connected directly to the feeder circuit and operated, for the most part, by itself in a working place. Overload protection and other electrical safety features were designed upon this basis. Such a procedure was dictated partly by the fact that the Bureau did not supervise the installation of machinery or circuits in the mines, and in most instances too little, if any, regulation over such matters was exercised by many of the State inspection departments. In the past the assumption of individual operation has been in keeping with general mining practice.

Hard facts point to the conclusion that machines and work systems must be selected with more care than in the past and that more rigid maintenance and inspection are required with the newer developments in mechanical mining.

It cannot be emphasized too strongly that efforts to prevent mine explosions of electrical origin should not cease with the mere purchase of permissible equipment. Equipment that has been abused and neglected is no longer trustworthy as a safeguard against electrical ignition of gas or coal dust. The safety valve on a boiler, the safety catches on a mine cage, and the

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gauzes in a safety lamp all must receive periodic inspection, cleaning, adjustment, and lubrication if they are to be relied upon any to function as intended. The same is true of permissible equipment. If bolts are omitted, if unauthorized changes are made, if holes are burned or broken through walls of explosion-proof housings, and if cables are poorly spliced on such equipment it can no longer be truly regarded as permissible because any one of these faulty conditions might cause an ignition. This demands well-trained electricians and mechanics who understand the safety features of permissible equipment, as well as for the correct supplies and replacement parts if the equipment is to be maintained properly.

Thorough inspection must include frequent checking of the insulation of machinery by means of suitable instruments such as "meggers" to find incipient faults before the insulation actually fails. The Bureau's engineers believe that repair made promptly upon the basis of conscientious use of a megger is one of the best safeguards against electric shock.

Grounding methods must be studied carefully to guard against disaster from such insulation failures as may occur in spite of the best precautions. Too frequently testing and protective grounding are practiced, if at all, only as nuisances that have to be tolerated rather than as insurance against worse calamities. A regulation requiring ground-wire connections inside explosion-proof enclosures has often been suggested because of frequent sparking when the ground connections are made externally. This is a truly deplorable picture of poor maintenance. In the first place the insulation of the machine has been allowed to fail through neglect to keep track of its condition. In the second place, the protective ground has been allowed to deteriorate to a point where sparking and overheating of the ground connection have occurred. Will hiding the evidence of neglect by placing the connection inside out of sight solve this problem? Certainly not; even though this procedure may be desirable to palliate the results of this neglect. Adequate frequent measurement, inspection and immediate repairs of insulation when evidence of deterioration is discovered alone will do so.

In the United States less attention has been paid to protective grounding in mines than in some foreign countries. This probably is one reason why proportionately more men are killed from electric shock here; a considerably larger loss in electrical failures or break-downs of electrical equipment undoubtedly results. Speaking broadly of mining conditions in the United States, there seems to be an unwillingness by the industry to provide adequate grounding for underground electrical equipment. This lack makes the problem of safeguarding equipment extremely difficult and leaves many mines in a state bordering on continuous hazard.

Some measure of protection against hazards resulting from the proximity and interconnection of several machines in the same locality is obtained by intelligent use of grounding conductors and fuses (or equivalent overload protection). In many instances such expedients alone are not sufficient to protect fully against the hazards introduced by concentration of electrical circuits and machinery.

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Even with single machines overload protective devices are not always capable of completely protecting against failure from overloads. Fuses with small enough current ratings to prevent sustained overloads often cannot be used without unnecessary interruptions of service. Overload circuit breakers with the various time-delay and thermal trips now available often can be used to better advantage to provide a greater degree of protection than can be given by fuses, but none of these protective devices provide complete protection from hazards of electric break-down. Moreover, no protection whatever appears to be given by such overload devices for some of the hazards introduced by concentration of machines, as, for instance, the condition illustrated by figure 3. The addition of some leakage device to insure automatic disconnection of faulty circuits or apparatus when the current flows in an abnormal path may be found necessary to assure reasonably safe installations.

Some attempt has been made to reduce the total amount of cable exposed in rooms. One system employs a main cable whose length when fully extended equals or nearly equals that of the completed room. The end toward the face terminates in one or more junction boxes with receptacles or sockets to take plugs attached to cables for the various machines. This permits restricting the length of the individual machine cables merely to that required for convenience in operation and movement of the several machines. In most cases 50-foot lengths are adequate for the purpose.

When shaker conveyors are used further reduction in amount of cable exposed in a room is obtained by the use of a multiple-circuit junction box. In one such system the junction box was placed at the entrance to the room, and three circuits were served, namely, (1) mining machine, (2) shaker conveyor, and (3) blower. As the conveyor drive and the blower were placed at or near the room entrance, the cables to them were relatively short. This left only the mining-machine and conveyor control cable to be carried to the face. The mining-machine cable was taken through a fused box (mounted on the mining machine), in which the cable was tapped for a drill circuit, which was protected by this fused switch. In this system the mining machine and control circuits were carried on insulators fastened to the roof or to posts. By comparison with systems employing mobile loaders it is apparent that the system just described offers a much safer arrangement, as far as cables are concerned. Undoubtedly mining-machine manufacturers can design a satisfactory outlet into which a plug may be inserted for connection of drills to cutting machines. To meet requirements of the Bureau of Mines such a design would have to include an interlocking mechanism that would make it impossible to insert or withdraw the plug while the contacts in the socket are alive. In addition, fuses or other suitable overload protection for the drill cable would have to be incorporated with these changes in the mining machine, and the cable would have to include a separate conductor for grounding the drill frame to the frame of the mining machine.

Although the cable-reel truck does not lend itself to conveyor systems of mining this does not prevent the adoption of a substitute. When the mining machine does not carry a main switch and overload protective device these features should be designed for skid-mounting with a hand-cable about 50 feet

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long for connecting the machine with the parts on the skid. The skid should include a reel or other arrangement for keeping the trailing cable coiled and out of the way. Where a reel is impractical two "knobs" with rounded surfaces can be mounted so as to permit winding the cable in "figure 8" fashion. One machine manufacturer has built a skid-mounted contactor case enclosing two contactors, an overload relay, and a small switch for use with shortwall machines in connection with conveyor mining. A 100-foot cable is used between the machine and skid. A mine operator using this contactor case requires the machine helper to be stationed at the skid while the machine is being sumped in, so that if the machine starts to come out he can immediately trip the small switch, which in turn causes the main contactors to open and cut off power from the machine.

Standardization Needed

Conveyors, particularly those of the shaker type, have been introduced so rapidly in the last year or two that the experimental stage apparently has not been passed as to both equipment and methods of operation. Various types of control are being tried, and different arrangements of electrical circuits are being used to accomplish the desired ends, which may vary according to conditions. In spite of all this the Bureau's engineers firmly believe that a certain amount of standardization is possible in meeting the requirements of safety.

The relatively brief period (6 to 10 days) required to complete rooms 300 feet or more in depth with shaker conveyors has an important bearing on the type of equipment that should be selected and the manner in which it should be installed. For example, some of the control equipment now in use was designed for mounting on posts, yet their weight and lack of portability for convenience in frequent movement has led, in some installations, to placing the control boxes on the mine floor, where they are subject to damage from water and falling material. At the same time hose conduit enclosing the cable between the control box and the motor that drives the conveyor also has been allowed to rest on the floor, where its life can be shortened appreciably by damage from contact with oil, water, and materials moved over it.

Lack of standardization is apparent in the length of hose conduit chosen for this duty. In some instances 6 to 10 feet of this conduit would have been enough, but actually 25 feet were employed. The excess length merely added an unwieldy bulk that obstructed passageways and made it difficult to move the equipment to a new location. Moreover, the excess length meant increased hazards by virtue of the greater amount of conduit exposed to damage by falls of roof and by other destructive elements. It may have been that the original plans called for a length greater than was found necessary in later plans, or it may have been that the length was supplied by the manufacturer without consideration for actual requirements. In either case the safer installation would be that in which the minimum hose conduit is used.

When it is not feasible to mount the control box on the conveyor drive itself or on mine props the Bureau considers it essential that the box be supported in some manner to keep it from direct contact with the floor. If

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the design of the box does not include such support a special "skid" should be made for that purpose. A properly constructed skid would be advantageous as it would provide a means for transporting the box to a new location without the necessity of taking it down from the last place and lifting it again at the next.

Push-button stations have been used widely to provide remote control for conveyor systems. These stations, when connected to the main control box by a suitable length of cable, give the operator and others, depending on the system adopted, a means of starting and stopping the conveyor at a distance from the driving mechanism. When the driving motor and its control box are placed at the mouth of a room there are times when it is extremely important to be able to control the conveyor from two or more points, especially in thin seams. For this reason a push-button station often is placed near the face of the room to enable the men to start and stop the conveyor from that point in emergencies or in routine operations such as adding pans to lengthen the conveyor. Various types of push-button stations are in use. Some are arranged so that the men at the face can only stop the conveyor, starting being left to the man at the discharge point. Others give control of starting and stopping at the face as well as at the discharge point. Both of these may be open to serious objection if they do not prevent starting from one point after the conveyor has been stopped from another point. Thus, if the men at the face have stopped the conveyor to lengthen it or make other adjustments they might be injured should it be started by some one at the discharge point. Conversely, if it has been stopped at the discharge point for want of empty cars or to make repairs the men at the face should not be able to start it and cause coal to be spilled or damage done to parts.

Although push-button stations are generally designed for stationary mounting, it is not always the custom under actual mining conditions to go to the trouble of mounting the station on a post in a room for conveyor mining where the face may be advancing as much as 40 feet in a day. Instead, the station is sometimes allowed to rest on the mine floor, where exposure to water and dirt may damage it. When it is not feasible to set posts for the support of push-button stations some other type of support is necessary. Such support should also include means for reeling or coiling the slack control cable that is not required until the room reaches its full depth.

In some instances control cables have been of light construction, such as is ordinarily supplied for vacuum sweepers and other household appliances. It has not been the practice to enclose these cables in conduit, hence they are not mechanically strong enough to withstand rough handling and damage from falling slate and coal. If the control circuit operates on 250 or 500 volts direct current, sparks resulting from the severing of conductors would be an ignition hazard in a gassy mine. The Bureau now requires that control cables for approved equipment have 600-volt insulation to assure greater mechanical strength by reason of the greater thickness of rubber necessary for this voltage. Furthermore, the conductor must not be smaller than No. 16 for two-conductor cable nor smaller than No. 18 for three-conductor cable.

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Wiring of mining equipment submitted to the Bureau for approval is required to have adequate mechanical and electrical protection, particularly that outside of locked or explosion-proof enclosures. To enforce this requirement with respect to cables or cords between push-button stations and control boxes by asking that these cables be protected by conduit, usually would prove impractical except for short runs at the discharge point. One of the latest developments in control for shaker-conveyor installations has been the use of dry cells with relays for operating the contactors in the control box. This has made it possible to reduce the potential on the control cord from that of the power circuit to that of the dry-cell battery. With properly designed relays, and suitable resistors or condensers, it is possible to reduce the intensity of sparking that might occur in the event of damage to the cable to a point where gas ignition is precluded. Along with this advantage there is also the consideration of the elimination of shock hazards from handling a push-button station and the cable connected to it. With these two hazards eliminated the requirement of conduit for control circuits of this type can be waived by the Bureau.

In the past it has been customary to require that protection against shock from contact with a push-button station be provided by grounding its case to that of the control box. With control at dry-cell battery voltages such grounding will not be necessary. However, unless a station operating on higher potentials is mounted on an insulating base the Bureau does not recommend use of the grounding connection mentioned. The explanation for this is that with grounded direct systems failure of insulation in the control box may cause the main motor current to divide and flow to ground through the small conductor in the control cable. Thus there would be danger of burning this cable, and the flame could ignite gas.

In recent years the Bureau of Mines has received a number of requests for approval of schemes involving two or more machines operating in the same working place or involving specifically or by inference some system of working in which a number of machines are used in the same locality and which are more or less dependent upon each other and whose electrical circuits are more or less interconnected. Such requests have been increasing. Some recent examples of this general character are cited:

1. A request for approval of a standard, direct-current, shortwall machine with its switch and fuse box mounted on a skid and modified to provide cable outlets to a conveyor and a coal drill.

2. A request for approval of a room-and-face conveyor combination using two motors, a single control with locking features, and a remote push button.

3. A request for approval of a junction box having eight interlocked plug connections for mining-machine and conveyor connections.

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4. A request for approvals to cover s system requiring a power-distribution center, a main conveyor, two transfer conveyors, and eight room conveyors. This scheme included an interlocked system of control between the various conveyors and plug and socket connections at various points.

The Bureau of Mines has in general declined, for several reasons, requests for approval under Schedule 2D that involve systems of mining or combinations of machines. In the first place Schedule 2D, as approved May 23, 1936, by Charles West, Acting Secretary of the Interior, authorizes the issuing of approvals for single complete machines only, and even a very liberal interpretation of the schedule requirements would not appear to permit consideration of many of the proposals for approval. Furthermore, the provisions in the schedule for control, overload, and other protection for electrical circuits have been drawn to satisfy the requirements of single machines; they therefore probably are not adequate for other circumstances. At the least it would appear desirable that some of the practices now merely recommended by the schedule should be made mandatory if approvals are to be granted for such cases. Finally, the lack of uniformity in the combinations of machines and systems proposed makes the task of equitably interpreting present requirements that do not specifically provide for such applications extremely difficult if not impossible.

Several questions arise when the present and possible future status of permissible machinery for use in concentrated mining practice is considered. Among these is the status of machines already approved. If an operator takes several permissible machines with separate approval plates into one room he may thereby have decreased the safety of each machine below that contemplated in the approval of the individual machine. Under present conditions the conclusion is that the operator alone is responsible for the increased hazards created by his action.

It is realized that mining conditions are leading rapidly to introduction of concentrated mining systems with the more extensive use of electrical machinery. Design, installation, and maintenance of new schemes should be earnestly considered with regard to safety. Otherwise, new hazards, particularly catastrophic hazards, may be introduced. The necessary precautions are not always taken with these new developments, and safety men are fearful of what may happen. On the other hand, suitable equipment properly installed and maintained may provide favorable safety conditions. The fact that concentrated workings will permit better supervision and allow easier enforcement of safety practices should work for safety.

The advisability and desirable nature and extent of automatic protection in cases of combinations of otherwise safe machines requires study and definition. It is becoming evident that former ideas and practices regarding protective devices and grounding methods for mining machinery must be modified somewhat to keep pace with development in mechanized mining if a satisfactory level of safety is to be maintained.

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